

(19)



Europäisches Patentamt
European Patent Office
Office européen des brevets



(11)

EP 1 154 519 A1

(12)

EUROPEAN PATENT APPLICATION

published in accordance with Art. 158(3) EPC

(43) Date of publication:

14.11.2001 Bulletin 2001/46

(51) Int Cl.7: **H01Q 21/30**, H01Q 23/00,
H01Q 11/08

(21) Application number: **99959815.4**

(86) International application number:
PCT/JP99/07029

(22) Date of filing: **15.12.1999**

(87) International publication number:
WO 01/45208 (21.06.2001 Gazette 2001/25)

(84) Designated Contracting States:

**AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE**

(71) Applicant: **MITSUBISHI DENKI KABUSHIKI
KAISHA**
Tokyo 100-8310 (JP)

(72) Inventors:

• **NISHINO, Tamotsu, Mitsubishi Denki K.K.**
Tokyo 100-8310 (JP)

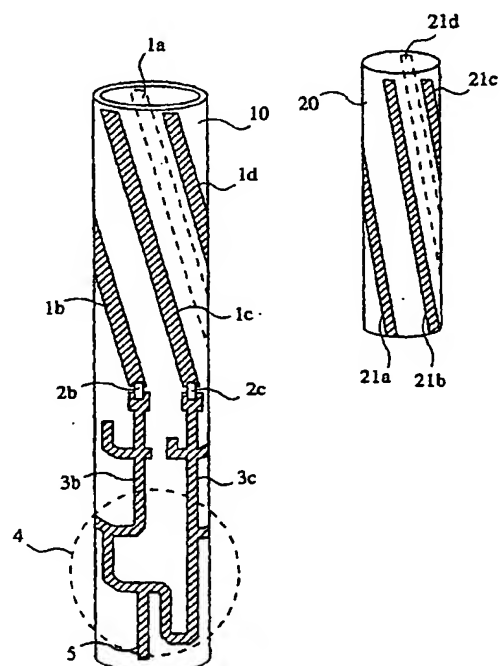
• **MIYAZAKI, Mōriyasu, Mitsubishi Denki K.K.**
Tokyo 100-8310 (JP)
• **ENDO, Tsutomu,**
Mitsubishi Denki Kabushiki Kaisha
Tokyo 100-8310 (JP)
• **OHWADA, Tetsu,**
Mitsubishi Denki Kabushiki Kaisha
Tokyo 100-8310 (JP)

(74) Representative: **Pfenning, Meinig & Partner**
Mozartstrasse 17
80336 München (DE)

(54) **ANTENNA DEVICE**

(57) An antenna device including matching circuits 4 corresponding to reflection coefficients of antenna elements 1a, 1b, 1c and 1d determined by taking into account the couplings between the antenna elements 1a, 1b, 1c and 1d occurring when the antenna elements 1a, 1b, 1c and 1d are excited with corresponding excitation amplitudes and excitation phases at each of operational frequencies.

FIG.4



EP 1 154 519 A1

Description

TECHNICAL FIELD

5 [0001] The present invention relates to an antenna device composed of a multi-element antenna operated at a plurality of frequencies.

BACKGROUND ART

10 [0002] Fig. 1 shows a construction of a conventional antenna device disclosed, for example, in U.S. Patent No. 5828348; this example is the case of a 4-element antenna operated at two frequencies, and matching circuits connected to the 4-element antenna are the same.

[0003] In Fig. 1, symbols 101a, 101b, 101c and 101d denote antenna elements, symbols 102a, 102b, 102c and 102d denote parasitic antenna elements, symbols 103a, 103b, 103c and 103d denote matching circuits connected respectively to the antenna elements 101a, 101b, 101c and 101d, symbols 104a and 104b denote divider/combiner circuits using double branch line circuits for dividing an inputted signal into two signals with a phase difference of 90 degrees, numeral 105 denotes a 180-degree divider/combiner circuit for dividing an inputted signal into two signals with a phase difference of 180 degrees, and numeral 106 denotes an input/output terminal.

20 [0004] Fig. 2 shows a cylindrical dielectric 30 on the surface of which an antenna portion composed of the antenna elements 101a, 101b, 101c, 101d and parasitic antenna elements 102a, 102b, 102c, 102d of Fig. 1 is provided. As shown in the figure, the antenna elements 101a, 101b, 101c and 101d are formed on the outer surface of the cylindrical dielectric 30, while the parasitic antenna elements 102a, 102b, 102c and 102d are formed on the inner surface of inside diameter of the cylindrical dielectric 30.

[0005] The operation of the antenna device will now be described.

25 [0006] A signal inputted to the input/output terminal 106 is divided by the 180-degree divider/combiner circuit 105 as signals having phases of 0 degree and -180 degrees. Thereafter, one of the signals is divided by the divider/combiner circuit 104a as signals having phases of 0 degree and -90 degrees, and the other is divided by the divider/combiner circuit 104b as signals having phases of -180 degrees and -270 degrees. At two operating frequencies f1 and f2, the 180-degree divider/combiner circuit 105 realizes a phase distribution of 0 degree and -180 degrees, while the divider/combiner circuits 104a and 104b realize a phase distribution of 0 degree and -90 degrees.

30 [0007] In order to realize matching for each of the antenna elements 101a, 101b, 101c and 101d at the two frequencies f1 and f2, a scattering matrix of the antenna is determined empirically or by calculation, and reflection coefficients in operation are determined using excitation amplitude and excitation phase. In this example, due to symmetry of the scattering matrix of the antenna and symmetry of the excitation phase, the reflection coefficients of the antenna elements 101a, 101b, 101c and 101d are equal. Accordingly, the matching circuits 103a, 103b, 103c and 103d connected respectively to the antenna elements 101a, 101b, 101c and 101d are the same.

35 [0008] The entire divider/combiner circuit composed of the 180-degree divider/combiner circuit 105 and the divider/combiner circuits 104a and 104b is large in size, as shown in Fig. 1. Thus, as shown in Fig. 2, the entire divider/combiner circuit cannot be formed on the cylindrical dielectric 30, and, therefore, only the antenna portion composed of the antenna elements 101a, 101b, 101c, 101d and the parasitic antenna elements 102a, 102b, 102c, 102d is formed on the cylindrical dielectric 30.

40 [0009] Fig. 3 shows a conventional small-type divider/combiner circuit constructed by combining T branches with lines of unequal lengths. In the figure, symbols 107a, 107b, 107c and 107d denote excitation terminals, numeral 108 denotes an input/output terminal, and symbols 109a, 109b, 109c and 109d denote lines having lengths according to desired excitation phases. The lengths of the lines are such that $109a < 109b < 109c < 109d$, and the excitation phase is progressively delayed in the order of 107a, 107b, 107c and 107d.

45 [0010] In the small-type divider/combiner circuit composed of T branches and lines of unequal lengths shown in Fig. 3, where the antenna device is operated at a plurality of frequencies, it is difficult to realize excitation with progressive phase shifts of a predetermined angle at all the frequencies. For example, where the lines 109a, 109b, 109c and 109d are set for excitation with symmetric phases by providing progressive phase shifts of 90 degrees at a frequency f1, the progressive phase shifts of 90 degrees cannot be achieved but asymmetric excitation results at a frequency f2 different from the frequency f1, and, therefore, the reflection coefficients at the antenna elements 101a, 101b, 101c and 101d are not equal to each other.

50 [0011] Since the conventional antenna devices are constituted as described above, there is the problem that the 180-degree divider/combiner circuit 105 and the divider/combiner circuits 104a and 104b for excitation with progressive phase shifts of a predetermined angle at operational frequencies f1 and f2 become very large, as shown in Fig. 1.

[0012] Therefore, where the antenna elements 101a, 101b, 101c, 101d, the matching circuits 103a, 103b, 103c, 103d, the divider/combiner circuits 104a, 104b and the 180-degree divider/combiner circuit 105 shown in Fig. 1 are

formed on respective substrates and the substrates are connected to each other by cables or other connecting mechanisms, there is the problem that the antenna device as a whole becomes very large.

[0013] Besides, in the case of the small-type divider/combiner circuit composed of the T branches and the lines of unequal lengths shown in Fig. 3, there is a problem that it is difficult to achieve excitation with progressive phase shifts of a predetermined angle at both the operational frequencies f_1 and f_2 , so that the reflection coefficients at the antenna elements 101a, 101b, 101c and 101d are not equal to each other, so that matching cannot be attained.

[0014] The present invention has been made to solve the above-mentioned problems. Accordingly, it is an object of the invention to obtain an antenna device which realizes smallness in size by using a small-type divider/combiner circuit such as the one shown in Fig. 3 and makes it possible to attain matching of a multi-element antenna at a plurality of operational frequencies by connecting different matching circuits respectively to the antenna elements 101a, 101b, 101c and 101d.

[0015] It is another object of the invention to obtain an antenna device which is reduced in overall size by integrally forming antenna elements, matching circuits and divider/combiner circuits on a cylindrical dielectric.

DISCLOSURE OF THE INVENTION

[0016] According to the present invention, there is provided an antenna device comprising a plurality of antenna elements operated at a plurality of frequencies, a divider/combiner circuit for exciting the plurality of antenna elements at desired phases, and matching circuits each connected to the antenna element at one end and connected to the divider/combiner circuit at the other end, the matching circuits corresponding to reflection coefficients of the antenna elements determined by taking into account the coupling between the antenna elements occurring when the antenna elements are excited with corresponding excitation amplitudes and excitation phases at each of the frequencies.

[0017] This is effective in that it is possible to attain impedance matching of each of the antenna elements at the plurality of operational frequencies.

[0018] According to the present invention, there is provided an antenna device wherein the divider/combiner circuit is constructed by combining T branches with different-length lines.

[0019] This is effective in that the antenna device can be made smaller in size.

[0020] According to the present invention, there is provided an antenna device wherein branch line circuits are used as the divider/combiner circuit.

[0021] This is effective in that the antenna device can be made smaller in size, and designing of the matching circuits can be easily realized.

[0022] According to the present invention, there is provided an antenna device wherein the plurality of antenna elements, the divider/combiner circuit and the matching circuits are integrally formed on a surface of a cylindrical dielectric.

[0023] This is effective in that the antenna device can be made smaller in size.

[0024] According to the present invention, there is provided an antenna device wherein parasitic antenna elements are disposed in the vicinity of said antenna elements.

[0025] This is effective in that a desired radiation pattern can be obtained from the antenna device.

[0026] According to the present invention, there is provided an antenna device wherein the plurality of antenna elements, the divider/combiner circuit and the matching circuits are integrally formed on a surface of a first cylindrical dielectric and the parasitic antenna elements are integrally formed on a surface of a second cylindrical dielectric different in inside diameter from the first cylindrical dielectric.

[0027] This is effective in that the antenna device can be made smaller in size.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028]

Fig. 1 is a development of an antenna device according to the prior art.

Fig. 2 shows a conventional cylindrical dielectric on which antenna elements are formed.

Fig. 3 shows a small-type divider/combiner circuit according to the prior art.

Fig. 4 shows the constitution of an antenna device according to Embodiment 1 of the present invention.

Fig. 5 is a development of the antenna device according to Embodiment 1 of the present invention.

Fig. 6 is a development of an antenna device according to Embodiment 2 of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

[0029] In order to describe the present invention in further detail, the best mode for carrying out the invention will now be described referring to the drawings.

Embodiment 1

[0030] Fig. 4 shows the constitution of an antenna device according to Embodiment 1 of the present invention, and Fig. 5 is a development of the antenna device of Fig. 4.

[0031] In Figs. 4 and 5, symbols 1a, 1b, 1c and 1d denote antenna elements, symbols 2a, 2b, 2c and 2d denote capacitors, symbols 3a, 3b, 3c and 3d denote matching circuits, numeral 4 denotes a divider/combiner circuit, and numeral 5 denotes an input/output terminal.

[0032] The divider/combiner circuit 4 is composed of T branches and lines of unequal lengths, and is characterized by simple structure and small size. The line extending from the input/output terminal 5 is coupled to two routes at a T branch, and each of the two routes has a T branch; thus, a total of four routes are provided. The distances in the respective routes from the input/output terminal 5 to the antenna elements 1a, 1b, 1c and 1d generally differ from each other in units of 1/4 of a wave length at a given frequency. The differences in line length cause the generation of phase differences of 0 degree, -90 degrees, -180 degrees and -270 degrees at the antenna elements 1a, 1b, 1c and 1d.

[0033] Where two frequencies are used in operation, it is difficult to attain phase differences of 0 degree, -90 degrees, -180 degrees and -270 degrees for both of the two frequencies f1 and f2. In this embodiment, therefore, the divider/combiner circuit 4 is so designed that excitation phases of 0 degree, -90 degree, -180 degree and -270 degree are obtained at the terminals on the side of the antenna elements 1a, 1b, 1c and 1d at one frequency f1 of the two operational frequencies.

[0034] In Fig. 4, numeral 10 denotes a cylindrical dielectric (first cylindrical dielectric), numeral 20 denotes a cylindrical dielectric (second cylindrical dielectric) smaller in inside diameter than the cylindrical dielectric 10, and symbols 21a, 21b, 21c and 21d denote parasitic antenna elements formed on the surface of the cylindrical dielectric 20.

[0035] A ground conductor is plated on a lower portion, outside the antenna elements 1a, 1b, 1c and 1d, of the inside of the cylindrical dielectric 10. No ground conductor is provided on a higher portion of the inside of the cylindrical dielectric 10 opposite the antenna elements 1a, 1b, 1c and 1d. The cylindrical dielectric 20 on which the parasitic antenna elements 21a, 21b, 21c and 21d are formed is so designed as to be fitted in the cylindrical dielectric 10. The cylindrical dielectric 20 is so disposed as to overlap a portion of the cylindrical dielectric 10 while in operation.

[0036] While the capacitors 2a, 2b, 2c and 2d are provided for matching in this embodiment, they can be omitted if characteristics provided by the capacitors 2a, 2b, 2c and 2d are included in the matching circuits 3a, 3b, 3c and 3d.

[0037] The operation of the antenna device will now be described.

[0038] Where the antenna elements 1a, 1b, 1c and 1d are arranged symmetrically, a scattering matrix as viewed from the terminals of the antenna elements 1a, 1b, 1c and 1d has a symmetric form given by the following Eq. 1.

$$\begin{aligned}
 S_{dd} &= S_{bb} = S_{cc} = S_{aa} \\
 S_{dc} &= S_{cd} = S_{ba} = S_{ab} = S_{bc} = S_{cb} = S_{ad} = S_{da} \\
 S_{ac} &= S_{ca} = S_{db} = S_{bd}
 \end{aligned}
 \tag{Eq. 1}$$

[0039] In the above Eq. 1, S_{ij} ($i = a$ to d , $j = a$ to d) indicates a coupling coefficient between an antenna element j and an antenna element i , and S_{11} indicates a reflection coefficient of the antenna element i , wherein it is assumed that the antenna elements other than the antenna element i are terminated in a no-reflection state. These values are obtained by measurement or calculation in a state where the parasitic antenna elements 21a, 21b, 21c and 21d are fitted.

[0040] A scattering matrix of the divider/combiner circuit 4 is obtained by measurement or calculation as a scattering matrix composed of five terminals, that is, the input/output terminal 5 and the four terminals of the antenna elements 1a, 1b, 1c and 1d. By using the scattering matrix as viewed from the terminals of the antenna elements 1a, 1b, 1c, 1d and the scattering matrix of the divider/combiner circuit 4, there are obtained excitation amplitudes and excitation phases of the antenna elements 1a, 1b, 1c and 1d at the terminals of the antenna elements 1a, 1b, 1c and 1d in a state where the antenna elements 1a, 1b, 1c and 1d are connected to the divider/combiner circuit 4.

[0041] In Fig. 5, the divider/combiner circuit 4 is here so designed that signals having excitation phases of 0 degree, -90 degrees, -180 degrees, -270 degrees and the same excitation amplitude are obtained at the terminals of the antenna elements 1a, 1b, 1c and 1d at a given frequency f1. At this time, as given by the following Eq. 2, the reflection coefficients Γ_a , Γ_b , Γ_c and Γ_d of the antenna elements 1a, 1b, 1c and 1d determined by taking into account the coupling between the antenna elements 1a, 1b, 1c and 1d at the terminals of the antenna elements 1a, 1b, 1c and 1d have the same value Γ_0 .

$$\Gamma_a = S_{aa} + S_{ab} \cdot e^{-j\frac{\pi}{2}} + S_{ac} \cdot e^{-j\pi} + S_{ad} \cdot e^{-j\frac{3\pi}{2}}$$

$$\Gamma_b = S_{bb} + S_{bc} \cdot e^{-j\frac{\pi}{2}} + S_{bd} \cdot e^{-j\pi} + S_{ba} \cdot e^{-j\frac{3\pi}{2}}$$

$$\Gamma_c = S_{cc} + S_{cd} \cdot e^{-j\frac{\pi}{2}} + S_{ca} \cdot e^{-j\pi} + S_{cb} \cdot e^{-j\frac{3\pi}{2}}$$

$$\Gamma_d = S_{dd} + S_{da} \cdot e^{-j\frac{\pi}{2}} + S_{db} \cdot e^{-j\pi} + S_{dc} \cdot e^{-j\frac{3\pi}{2}}$$

Eq. 2

[0042] In contrast, at a frequency f2 different from the frequency f1, the excitation phases at the terminals of the antenna elements 1a, 1b, 1c and 1d are not equal to 0 degree, -90 degrees, -180 degrees and -270 degrees, but have slightly deviated values. Assuming the excitation phases to be p1 degrees, p2 degrees, p3 degrees and p4 degrees and assuming the excitation amplitudes to be M1, M2, M3 and M4, the reflection coefficients Γ_1 , Γ_2 , Γ_3 and Γ_4 determined by taking into account the coupling of the antenna elements 1a, 1b, 1c and 1d at the terminals of the antenna elements 1a, 1b, 1c and 1d have different values given by the following Eq. 3.

$$\Gamma_1 = (S_{aa} \cdot M_1 e^{jp_1} + S_{ab} \cdot M_2 e^{jp_2} + S_{ac} \cdot M_3 e^{jp_3} + S_{ad} \cdot M_4 e^{jp_4}) / M_1 e^{jp_1}$$

$$\Gamma_2 = (S_{ba} \cdot M_1 e^{jp_1} + S_{bb} \cdot M_2 e^{jp_2} + S_{bc} \cdot M_3 e^{jp_3} + S_{bd} \cdot M_4 e^{jp_4}) / M_2 e^{jp_2}$$

$$\Gamma_3 = (S_{ca} \cdot M_1 e^{jp_1} + S_{cb} \cdot M_2 e^{jp_2} + S_{cc} \cdot M_3 e^{jp_3} + S_{cd} \cdot M_4 e^{jp_4}) / M_3 e^{jp_3}$$

$$\Gamma_4 = (S_{da} \cdot M_1 e^{jp_1} + S_{db} \cdot M_2 e^{jp_2} + S_{dc} \cdot M_3 e^{jp_3} + S_{dd} \cdot M_4 e^{jp_4}) / M_4 e^{jp_4}$$

Eq. 3

[0043] The matching circuits 3a, 3b, 3c and 3d are so sized as to match the reflection coefficient Γ_0 of the antenna elements 1a, 1b, 1c and 1d given by Eq. 2 above at the frequency f1, and to match the reflection coefficients Γ_1 , Γ_2 , Γ_3 and Γ_4 of the antenna elements 1a, 1b, 1c and 1d give by Eq. 3 at the frequency f2. Therefore, the matching circuits 3a, 3b, 3c and 3d differ in size.

[0044] The excitation amplitudes and the excitation phases of the antenna elements 1a, 1b, 1c and 1d obtained by the above calculation have values somewhat deviated from the initial values, due to the connection of the differently-sized matching circuits 3a, 3b, 3c and 3d. Taking into account the characteristics of the matching circuits 3a, 3b, 3c and 3d connected, excitation amplitudes and excitation phases of the antenna elements 1a, 1b, 1c and 1d are newly calculated, and the matching circuits 3a, 3b, 3c and 3d are re-designed using the newly obtained excitation amplitudes and excitation phases. This process is repeated, so as to accomplish more accurate designing.

[0045] By designing the sizes of the matching circuits 3a, 3b, 3c and 3d to match the different reflection coefficients of the antenna elements 1a, 1b, 1c and 1d in the manner as described above, it is possible to realize an antenna device having excellent characteristics even when a divider/combiner circuit 4 incapable of realizing the excitation phases of 0 degree, -90 degree, -180 degree and -270 degree at the two frequencies f1 and f2 is used.

[0046] Besides, by using the divider/combiner circuit 4 which is simple in structure and small in size, it is possible to integrally form the antenna elements 1a, 1b, 1c, 1d, the capacitors 2a, 2b, 2c, 2d, the matching circuits 3a, 3b, 3c, 3d and the divider/combiner circuit 4 on the cylindrical dielectric 10.

[0047] Furthermore, the cylindrical dielectric 20 is so disposed as to overlap a portion of the cylindrical dielectric 10 while in operation and the parasitic antenna elements 21a, 21b, 21c and 21d are disposed in the vicinity of the antenna elements 1a, 1b, 1c and 1d, so that a desired radiation pattern can be radiated from the antenna device.

[0048] While two operational frequencies are used in this embodiment, three or more frequencies may be adopted. In addition, while four antenna elements are used in this embodiment, the requirement is that at least two antenna elements are used. Further, while four parasitic antenna elements are used in this embodiment, the requirement is that at least two parasitic antenna elements are used.

[0049] Besides, while the divider/combiner circuit 4 in this embodiment is so designed that the same excitation amplitude and the excitation phases of 0 degree, -90 degree, -180 degrees and -270 degrees are realized at the terminals on the side of the antenna elements 1a, 1b, 1c and 1d at the frequency f1 and that different excitation amplitudes and different excitation phases are realized at the frequency f2, the divider/combiner circuit 4 may also be so designed that different excitation amplitudes and excitation phases as close as possible to 0 degree, -90 degrees, -180 degrees and -270 degrees are realized at both of frequencies f1 and f2.

[0050] While the parasitic antenna elements 21a, 21b, 21c and 21d are integrally formed on the cylindrical dielectric 20 smaller in inside diameter than the cylindrical dielectric 10 and the cylindrical dielectric 20 is inserted in the cylindrical dielectric 10 in this embodiment, the parasitic antenna elements 21a, 21b, 21c and 21d may be integrally formed on a cylindrical dielectric 20 larger in inside diameter than the cylindrical dielectric 10 so that the cylindrical dielectric 10 can be inserted in the cylindrical dielectric 20. In addition, the parasitic antenna elements 21a, 21b, 21c and 21d may be integrally formed on the inner surface of the cylindrical dielectric 10, instead of using the cylindrical dielectric 20, as long as the height of the cylindrical dielectric 10 is maintained.

[0051] As described above, according to this Embodiment 1, the matching circuits 3a, 3b, 3c and 3d are made to correspond to the reflection coefficients of the antenna elements 1a, 1b, 1c and 1d determined by taking into account the coupling between the antenna elements 1a, 1b, 1c and 1d occurring when the antenna elements 1a, 1b, 1c and 1d are excited according to the corresponding excitation amplitudes and excitation phases at operational frequencies, so that the impedance matching can be attained.

[0052] In addition, according to this Embodiment 1, the divider/combiner circuit 4 is composed of T branches and lines of unequal lengths simple in structure and small in size, so that the antenna device can be made smaller in size.

[0053] Further, according to this Embodiment 1, a plurality of antenna elements 1a, 1b, 1c, 1d, the divider/combiner circuit 4 and the matching circuits 3a, 3b, 3c, 3d are integrally formed on the surface of the cylindrical dielectric 10, so that the antenna device can be made smaller in size.

[0054] Furthermore, according to this Embodiment 1, the parasitic antenna elements 21a, 21b, 21c and 21d are disposed in the vicinity of the antenna elements 1a, 1b, 1c and 1d at the time of operation, so that a desired radiation pattern can be radiated from the antenna device.

[0055] Furthermore, according to this Embodiment 1, the parasitic antenna elements 21a, 21b, 21c and 21d are integrally formed on the surface of the cylindrical dielectric 20 different in inside diameter from the cylindrical dielectric 10, so that the device can be made smaller in size.

Embodiment 2

[0056] Fig. 6 is a development of an antenna device according to Embodiment 2 of the present invention. In this embodiment, the divider/combiner circuit 4 in Embodiment 1 is replaced by a divider/combiner circuit using branch line circuits.

[0057] In Fig. 6, symbols 1a, 1b, 1c and 1d denote antenna elements, symbols 2a, 2b, 2c and 2d denote capacitors, symbols 3a, 3b, 3c and 3d denote matching circuits, numeral 8 denotes a divider/combiner circuit using branch line circuits, and numeral 5 denotes a signal input/output terminal.

[0058] The divider/combiner circuit 8 is larger than the divider/combiner circuit 4 composed of T branches and lines of unequal lengths in Embodiment 1, but is smaller than that using the divider/combiner circuits 104a, 104b, using the double branch circuits, and the 180-degree divider/combiner circuit 105 according to the prior art. In the divider/combiner circuit 8, a loop line connected to the input/output terminal 5 gives a phase difference of 180 degrees, and the subsequent lines give phase differences of 90 degrees.

[0059] Where two operational frequencies are used, it is difficult to realize phase differences of 0 degree, -90 degrees, -180 degrees and -270 degrees at both of the frequencies f_1 and f_2 ; in this embodiment, therefore, the divider/combiner circuit 8 is so designed that excitation phases of 0 degree, -90 degrees, -180 degrees and -270 degrees are attained at terminals on the side of the antenna elements 1a, 1b, 1c and 1d at one frequency f_1 of the two operational frequencies.

[0060] The operation of the antenna device will now be described.

[0061] Where the antenna elements 1a, 1b, 1c and 1d are disposed symmetrically, the scattering matrix as viewed from the terminals of the antenna elements 1a, 1b, 1c and 1d assumes a symmetric form as shown in Eq. 1 above. In Fig. 6, the divider/combiner circuit 8 here is so designed that signals having excitation phases of 0 degree, -90 degrees, -180 degrees and -270 degrees and the same excitation amplitude are obtained at the terminals on the side of the antenna elements 1a, 1b, 1c and 1d at a certain frequency f_1 . In this case, from Eq. 2 above, the reflection coefficients Γ_a , Γ_b , Γ_c and Γ_d of the antenna elements 1a, 1b, 1c and 1d determined by taking into account the coupling between the antenna elements 1a, 1b, 1c and 1d at the terminals of the antenna elements 1a, 1b, 1c and 1d have the same value Γ_0 .

[0062] In contrast, at a frequency f_2 different from the frequency f_1 , the excitation phases at the terminals of the antenna elements 1a, 1b, 1c and 1d are generally not 0 degree, -90 degrees, -180 degrees and -270 degrees but have slightly deviated values. Assuming the actual excitation phases to be p_1 degrees, p_2 degrees, p_3 degrees and p_4 degrees and the excitation amplitudes to be M_1 , M_2 , M_3 and M_4 , the reflection coefficients Γ_1 , Γ_2 , Γ_3 and Γ_4 determined by taking into account the couplings between the antenna elements 1a, 1b, 1c and 1d at the terminals of the antenna elements 1a, 1b, 1c and 1d have different values as given by Eq. 3 above.

[0063] The matching circuits 3a, 3b, 3c and 3d are so designed as to match the reflection coefficients Γ_0 of the antenna elements 1a, 1b, 1c and 1d given by Eq. 2 above at the frequency f_1 and to match the reflection coefficients Γ_1 , Γ_2 , Γ_3 and Γ_4 of the antenna elements 1a, 1b, 1c and 1d given by Eq. 3 above at the frequency f_2 . Accordingly,

the matching circuits 3a, 3b, 3c and 3d are different in size.

[0064] The operation of this embodiment is generally the same as the operation of Embodiment 1, but is characterized in that, since the divider/combiner circuit 8 is composed using the branch line circuits, the excitation phases of the antenna elements 1a, 1b, 1c and 1d at the two frequencies f1 and f2 are not seriously deviated from 0 degree, -90 degrees, -180 degrees and -270 degrees, so that the matching circuits 3a, 3b, 3c and 3d differ only slightly from each other and it is easy to design the matching circuits 3a, 3b, 3c and 3d.

[0065] In this manner the sizes of the matching circuits 3a, 3b, 3c and 3d are designed so as to correspond to the different reflection coefficients of the terminals of the antenna elements 1a, 1b, 1c and 1d, so that an antenna device having excellent characteristics can be realized even when a divider/combiner circuit 8 which cannot necessarily realize the excitation phases of 0 degree, -90 degrees, -180 degrees and -270 degrees at the two frequencies f1 and f2 is used.

[0066] In addition, the use of the small type divider/combiner circuit 8 makes it possible to integrally form the antenna elements 1a, 1b, 1c, 1d, the capacitors 2a, 2b, 2c, 2d, the matching circuits 3a, 3b, 3c, 3d and the divider/combiner circuit 8 on the cylindrical dielectric 10.

[0067] Further, the cylindrical dielectric 20 is so disposed while in operation as to overlap a portion of the cylindrical dielectric 10 and the parasitic antenna elements 21a, 21b, 21c and 21d are disposed in the vicinity of the antenna elements 1a, 1b, 1c and 1d, so that a desired radiation pattern can be radiated from the antenna device.

[0068] While two operational frequencies are used in this embodiment, the requirement is that at least two frequencies are used. Besides, while four antenna elements are used in this embodiment, the requirement is that at least two antennal elements are used. Further, while four parasitic antenna elements are used in this embodiment, the requirement is that one or a plurality of parasitic antennas are used.

[0069] While the divider/combiner circuit 8 in this embodiment is so designed that the same excitation amplitude and excitation phases of 0 degree, -90 degrees, -180 degrees and -270 degrees are obtained at the terminals of the antenna elements 1a, 1b, 1c and 1d at the frequency f1 and that different excitation amplitudes and different excitation phases are obtained at the frequency f2, the divider/combiner circuit 8 may be so designed that different excitation amplitudes and excitation phases as close as possible to 0 degree, -90 degrees, -180 degrees and -270 degrees are obtained at both of the two frequencies f1 and f2.

[0070] While the parasitic antenna elements 21a, 21b, 21c and 21d are integrally formed on the cylindrical dielectric 20 smaller in inside diameter than the cylindrical dielectric 10 and the cylindrical dielectric 20 is inserted in the cylindrical dielectric 10 in this embodiment, the parasitic antenna elements 21a, 21b, 21c and 21d may be integrally formed on a cylindrical dielectric 20 larger in inside diameter than the cylindrical dielectric 10 so that the cylindrical dielectric 10 can be inserted in the cylindrical dielectric 20. Besides, the parasitic antenna elements 21a, 21b, 21c and 21d may be integrally formed on the inner surface of the cylindrical dielectric 10, instead of using the cylindrical dielectric 20, as long as the height of the cylindrical dielectric 10 is maintained.

[0071] As described above, according to this Embodiment 2, the matching circuits 3a, 3b, 3c and 3d are designed to correspond to the reflection coefficients of the antenna elements 1a, 1b, 1c and 1d determined by taking into account the coupling between the antenna elements 1a, 1b, 1c and 1d occurring when the antenna elements 1a, 1b, 1c and 1d are excited with corresponding excitation amplitudes and excitation phases, so that impedance matching can be attained.

[0072] In addition, according to this Embodiment 2, the branch line circuits are used as the divider/combiner circuit 8, so that the antenna device can be made smaller in size.

[0073] Further, according to this Embodiment 2, a plurality of antenna elements 1a, 1b, 1c, 1d, the divider/combiner circuit 8 and the matching circuits 3a, 3b, 3c, 3d are integrally formed on the surface of the cylindrical dielectric 10, so that the antenna device can be made smaller in size.

[0074] Furthermore, according to this Embodiment 2, the parasitic antenna elements 21a, 21b, 21c and 21d are disposed in the vicinity of the antenna elements 1a, 1b, 1c and 1d at the time of operation, so that a desired radiation pattern can be radiated from the antenna device.

[0075] Furthermore, according to this Embodiment 2, the parasitic antenna elements 21a, 21b, 21c and 21d are integrally formed on the surface of the cylindrical dielectric 20 different from the cylindrical dielectric 10 in inside diameter, so that the antenna device can be made smaller in size.

Industrial Applicability

[0076] As has been described above, the antenna device according to the present invention comprises matching circuits corresponding to antenna elements and is thereby suitable for reduction in size.

Claims

1. An antenna device comprising a plurality of antenna elements operated at a plurality of frequencies, a divider/combiner circuit for exciting said plurality of antenna elements at desired phases, and matching circuits each
5 connected to said antenna element at one end and connected to said divider/combiner circuit at the other end, said matching circuits corresponding to reflection coefficients of said antenna elements determined by taking into account the coupling between said antenna elements occurring when said antenna elements are excited with corresponding excitation amplitudes and excitation phases at each of said frequencies.
- 10 2. The antenna device according to claim 1, wherein said divider/combiner circuit is constructed by combining T branches with lines of unequal lengths.
3. The antenna device according to claim 1, wherein branch line circuits are used as said divider/combiner circuit.
- 15 4. The antenna device according to claim 1, wherein said plurality of antenna elements, said divider/combiner circuit and said matching circuits are integrally formed on a surface of a cylindrical dielectric.
5. The antenna device according to claim 1, wherein parasitic antenna elements are disposed in the vicinity of said antenna elements.
20
6. The antenna device according to claim 5, wherein said plurality of antenna elements, said divider/combiner circuit and said matching circuits are integrally formed on a surface of a first cylindrical dielectric and said parasitic antenna elements are integrally formed on a surface of a second cylindrical dielectric different in inside diameter from said
25 first cylindrical dielectric.

FIG.1

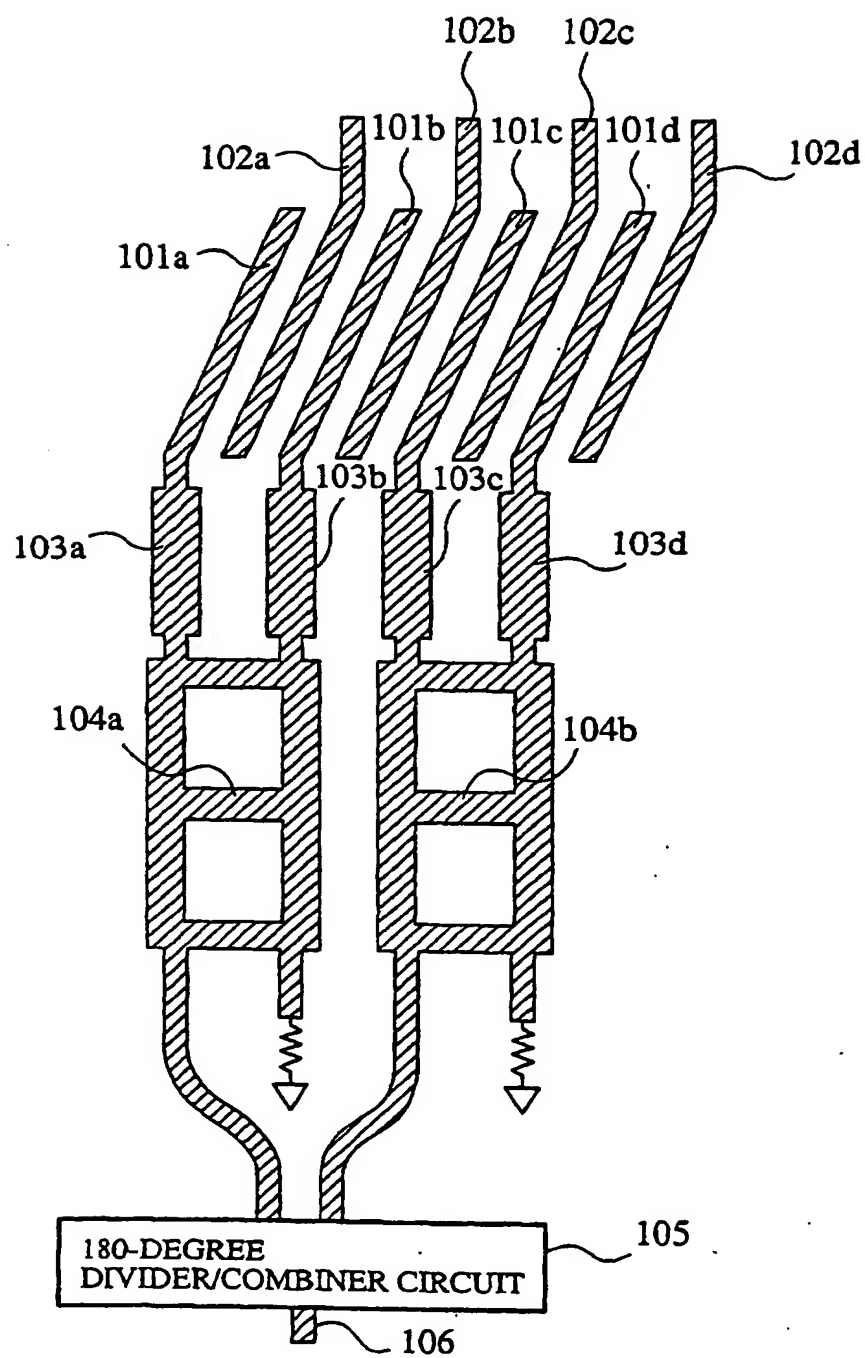


FIG.3

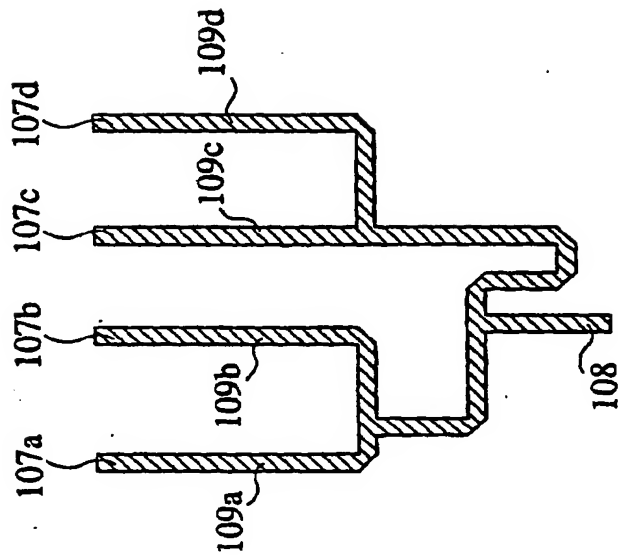


FIG.2

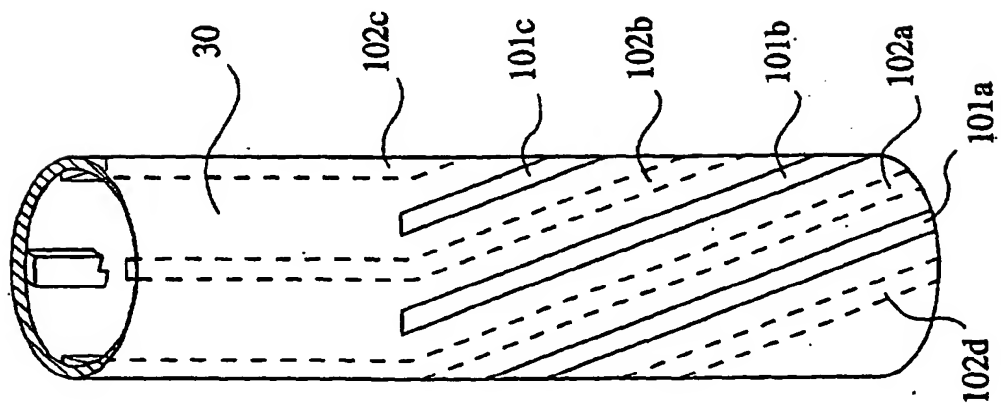


FIG.4

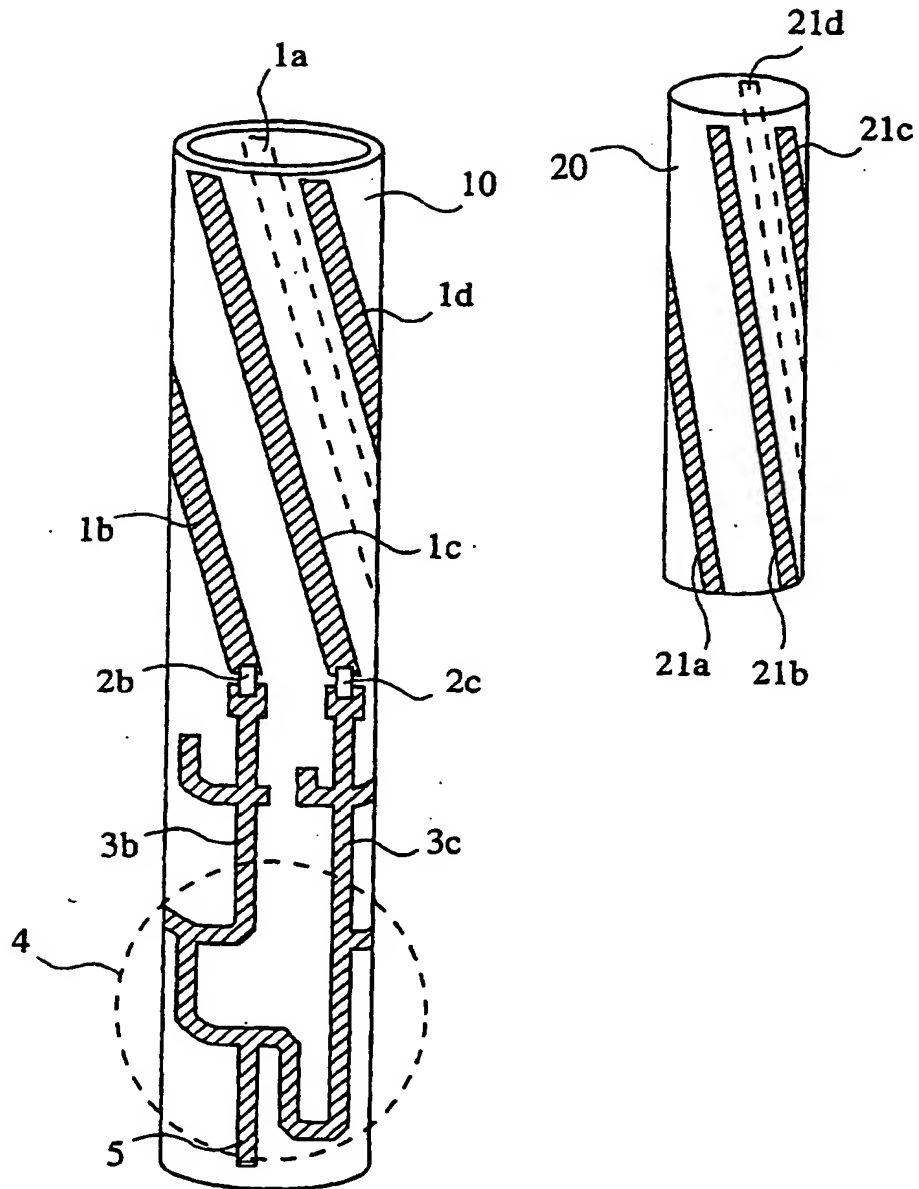


FIG.5

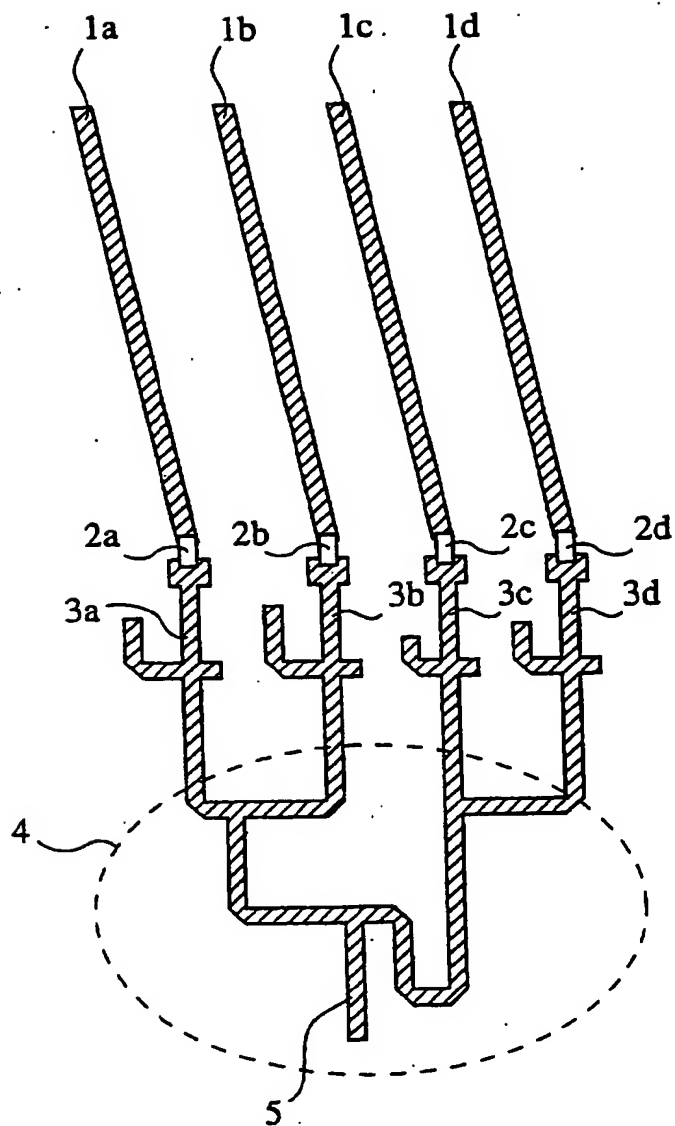
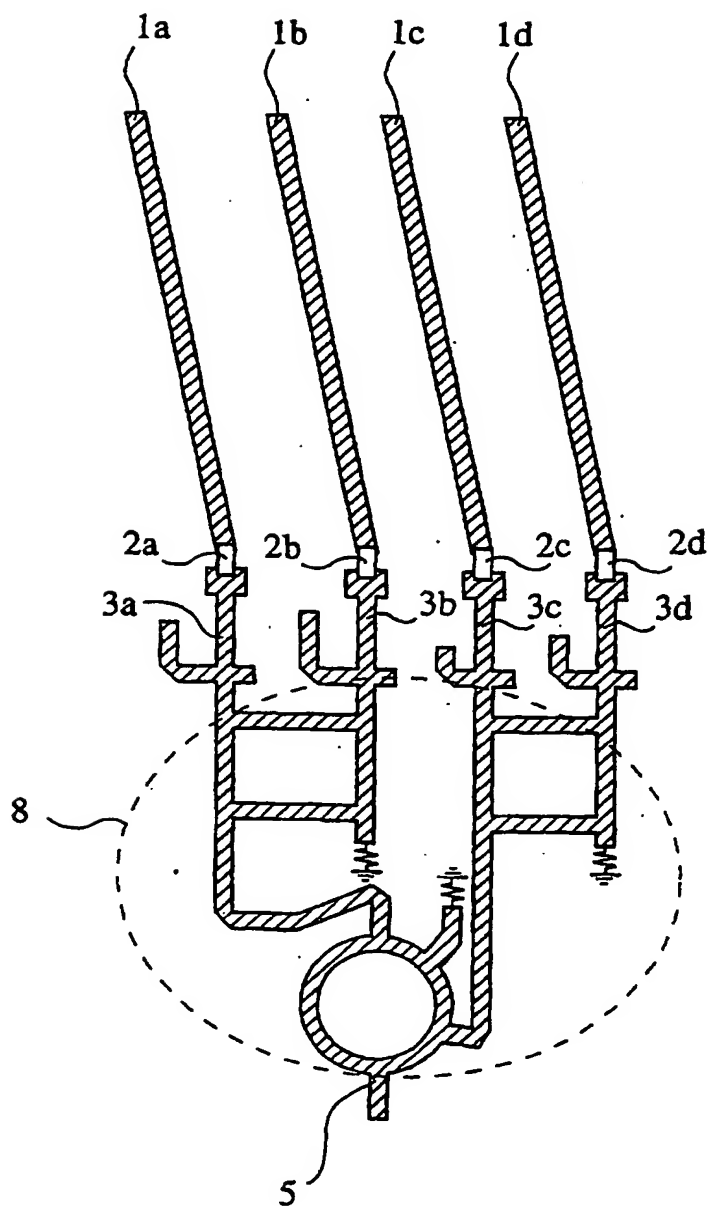


FIG.6



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP99/07029

A. CLASSIFICATION OF SUBJECT MATTER Int. Cl. ⁷ H01Q21/30, H01Q23/00, H01Q11/08		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) Int. Cl. ⁷ H01Q21/30, H01Q23/00, H01Q11/08		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Jitsuyo Shinan Koho 1926-1996 Jitsuyo Shinan Toroku Koho 1996-2000 Kokai Jitsuyo Shinan Koho 1971-2000 Toroku Jitsuyo Shinan Koho 1994-2000		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP, 5-41676, A (Japan Radio Co., Ltd.), 19 February, 1993 (19.02.93) (Family: none)	1-6
Y	JP, 10-308624, A (NEC Corporation), 17 November, 1998 (17.11.98) (Family: none)	1-6
Y	JP, 5-251910, A (Nippon Telegr. & Teleph. Corp. <NTT>), 28 September, 1993 (28.09.93) (Family: none)	1-6
Y	JP, 11-74720, A (Antenna Giken K.K.), 16 March, 1999 (16.03.99) (Family: none)	1-6
Y	JP, 10-256824, A (NEC Corporation), 25 September, 1998 (25.09.98) (Family: none)	1-6
Y	JP, 10-98320, A (Matsushita Electric Ind. Co., Ltd.), 14 April, 1998 (14.04.98) (Family: none)	1-6
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 29 February, 2000 (29.02.00)		Date of mailing of the international search report 14 March, 2000 (14.03.00)
Name and mailing address of the ISA/ Japanese Patent Office		Authorized officer
Facsimile No.		Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)

**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ **BLACK BORDERS**
- ☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**
- ☒ **FADED TEXT OR DRAWING**
- ☐ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**
- ☐ **SKEWED/SLANTED IMAGES**
- ☐ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**
- ☐ **GRAY SCALE DOCUMENTS**
- ☐ **LINES OR MARKS ON ORIGINAL DOCUMENT**
- ☐ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**
- ☐ **OTHER:** _____

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.